



effect of current spreading to enhance the light-emitting efficiency of the device. However, since the electrode 13 must be very thin to become light-transmitting, its lateral resistance will be great and thus its effect of current spreading will be very limited. Besides, since the electrode 13 is placed over the main light-emitting surface, even the electrode 13 is light-transmissive, it still will reduce the light-emitting efficiency of the device.

USP 4,476,620 discloses a flip-chip GaN-based light-emitting device as shown in Fig. 2, wherein the two electrodes 21 and 22 of an LED die are directly stuck on certain places of a lead frame 23. In such a flip-chip GaN-based light-emitting device, the emitted light can directly pass through the transparent substrate (such as a sapphire substrate) to the outside. There is no soldering pad in the main light-emitting surface of the flip-chip light-emitting device, and thus the light-emitting surface as well as the light-emitting efficiency will not be affected by the soldering pad. However, only about half the light emitted from the prior flip-chip GaN-based light-emitting device can directly pass through the transparent substrate to the outside. The other half of the light is directed to the electrodes (21 and 22) and the lead frame 23. Therefore, the prior device cannot achieve an effective result. Furthermore, the prior flip-chip GaN-based light-emitting device disclosed in USP 4,476,620 does not provide the current spreading effect, and thus merely the place where the electrode is located can have an effective light-emitting result while the other place cannot achieve a good light-emitting result.

In view of the above, how to substantially improve the light-emitting efficiency of a GaN-based light-emitting device is still a problem for the industry.

### **Summary of the Invention**

The main object of the present invention is to substantially improve the light-emitting efficiency of a GaN-based light-emitting device. The light-emitting device according to the present invention is a flip-chip light-emitting device.

Therefore, there is no soldering pad in its main light-emitting surface. Additionally, the light-emitting device according to the present invention has an electrode that has good reflectivity of light and can provide effective current spreading effect. Therefore, the light directed to the electrode can be reflected by the electrode to the outside through the transparent substrate, and thus substantially increase the light-emitting efficiency of the whole device. Further, the electrode can have sufficient size and thickness to provide effective current spreading effect, such that the light-emitting diode can achieve its best light-emitting result.

A flip-chip light-emitting device according to a first embodiment of the present invention comprises a transparent substrate, a semiconductor stacked structure arranged over a main surface of the transparent substrate wherein the stacked structure comprises an n-type GaN-based III-V Group compound semiconductor layer adjacent to said main surface and a p-type GaN-based III-V Group compound semiconductor layer adjacent to the n-type semiconductor layer, a first electrode being in electrical contact with the n-type semiconductor layer, and a second electrode being in electrical contact with the p-type semiconductor layer, wherein the second electrode has good reflectivity of light and covers most of the outer surface of the p-type semiconductor layer. In an alternative embodiment of the present invention, the positions of the n-type and p-type semiconductor layers are switched, and the electrode being in contact with the n-type semiconductor layer has good reflectivity of light and covers most outer surface of the n-type semiconductor layer.

### **Brief Description of the Drawings**

The technical content and features of the present invention will be more readily apparent from the following detailed description of the preferred embodiments with reference to the accompanying drawings in which:

Fig. 1 is a cross-sectional view illustrating a prior GaN-based light-emitting device;

Fig. 2 is a cross-sectional view illustrating a prior flip-chip GaN-based light-emitting device;

Fig. 3 is a schematic cross-sectional view illustrating a light-emitting diode according to an embodiment of the present invention;

Fig. 4 is a schematic cross-sectional view of the light-emitting diode of Fig. 3 mounted on a base in the form of flip-chip.

### **Detailed Description of the Preferred Embodiments**

The main object of the present invention is to substantially improve the light-emitting efficiency of a GaN-based light-emitting device. The light-emitting device according to the present invention has an electrode that has good reflectivity of light and can provide effective current spreading effect. Therefore, the light directed to the electrode can be reflected by the electrode to the outside, and thus substantially increase the light-emitting efficiency of the whole device. Further, the electrode can have sufficient size and thickness to provide effective current spreading effect, so that the light-emitting diode can achieve its best light-emitting result.

Fig. 3 illustrates a light-emitting diode according to an embodiment of the present invention. The diode structure 30 comprises a transparent substrate 31 which can be made of sapphire, glass, silicon carbide (SiC), gallium nitride (GaN), gallium phosphide (GaP) or other transparent materials. A semiconductor stacked structure is arranged over a main surface of the transparent substrate 31. The stacked structure comprises an n-type GaN-based III-V Group compound semiconductor layer adjacent to said main surface and a p-type GaN-based III-V Group compound semiconductor layer adjacent to the n-type semiconductor layer. In this embodiment, the stacked structure also comprises an active layer 34

placed between the n-type GaN-based III-V Group compound semiconductor layer and the p-type GaN-based III-V Group compound semiconductor layer, while in other embodiments of the present invention, it is possible that the stacked structure does not include the active layer 34. The method for manufacturing the stacked structure is well known in the art, and thus it is unnecessary to detail it here. An electrode 35 is located in a window, that is formed by an etching process, and in electrical contact with the n-type semiconductor layer 32. An electrode 36 is arranged over most of the outer surface of the p-type semiconductor layer 33. Since there are no special limitations on the size and thickness of the electrode 36, the shape and size of the electrode 36 can be designed to achieve the best current spreading result, and thus substantially increase the light-emitting efficiency. In addition, the material of the electrode 36 is chosen to be of high reflectivity of light. Therefore, the light directed to the electrode 36 can be reflected by the electrode 36 to the direction of the transparent substrate, and thus further increase the light-emitting efficiency.

In the present invention, the electrode 36 can be of a multi-layer structure comprising a light-transmitting conductive layer and a layer of aluminium (Al) or silver (Ag). In an embodiment of the present invention, the electrode 36 can be of a nickel/gold/titanium/aluminium (Ni/Au/Ti/Al) multi-layer structure, wherein nickel gold (Ni/Au) is formed to be a light-transmitting metal layer directly covering the p-type semiconductor layer 33, and then a titanium (Ti) layer is formed on the Ni/Au layer, and finally an aluminium (Al) layer is formed on the Ti layer. The electrode 36 is required to be of both low ohmic contact resistance and high reflectivity of light. Ni/Au is one of the materials that can be formed as a good light-transmitting ohmic contact layer for a p-type GaN-based III-V Group compound semiconductor layer. Al layer can be of good reflectivity of light. However, in a high temperature, Al and Au will diffuse into each other and destroy the reflectivity of Al. Therefore a Ti layer is used to be a diffusion barrier

between Al and Au. Ti layer itself is also of good reflectivity of light. In other embodiments of the present invention, the electrode 36 can be of a multi-layer structure of ITO Al or ITO Ag, wherein ITO (Indium-Tin Oxide) is formed as a light-transmitting conductive layer and the reflectivity is provided by the Al layer or Ag layer.

In the embodiment shown in Fig. 3, an insulating layer 37 can be coated on the side surface and upper surface of the diode 30 while merely exposing a portion of each electrode that is used to contact the electrode of a base. The material of the insulating layer can be  $\text{SiO}_x$ ,  $\text{SiN}_y$ , etc.. The insulating layer 37 is to protect and isolate the p/n junction, to avoid short circuit caused by conductive glue and to avoid leakage.

Fig. 4 is a schematic view showing the light-emitting diode of Fig. 3 mounted on a base in the form of flip-chip. The base 40 can be a known conductive lead frame, a glass lead frame, a circuit board or a thin-film circuit. Using a conductive lead frame or a glass lead frame as the base, the final device will be a discrete light-emitting device, while using a circuit board or a thin-film circuit as the base, the light-emitting device will be in the form of surface mounted device (SMD). The base 40 has conductive portions 41 and 42 that function as a positive electrode and a negative electrode, respectively. Conductive glue 43 is applied by a machine on the positive and negative electrodes of the base 40. Then, the light-emitting diode 30 is turned over to let the transparent substrate be the top layer and the electrodes 35 and 36 face down. After determining the correct polarities of the electrodes 35 and 36, the electrodes 35 and 36 are connected to the conductive glue 43 so as to be fixed on the base and be coupled to the electrodes of the base. Finally, the conductive glue is baked in a suitable temperature during a predetermined time to complete the manufacture of the light-emitting device.

In this embodiment, about half of the light emitted from the p-n junction or the

active layer of the light-emitting device will directly pass through the transparent substrate to the outside, while the other half of the light will direct to the electrode 36. Since the electrode 36 has high efficiency of reflectivity, it can reflect the light through the transparent substrate to the outside, and thus increase the light-emitting efficiency. Further, the electrode 36 provides the current spreading effect to additionally increase the light-emitting efficiency of the light-emitting diode.

In other embodiments of the present invention, the places of the n-type semiconductor layer and the p-type semiconductor layer can be exchanged. In such embodiments, the electrode over the n-type semiconductor layer will be of high reflectivity of light and provides current spreading effect. Said electrode can be of a multi-layer structure comprising a light-transmitting conductive layer and a layer of aluminium (Al) or silver (Ag). In embodiments of the present invention, said electrode can be of a multi-layer structure of Ti/Al, Ti/Ag, ITO/Al or ITO/Ag.

The technical features and technical contents of the present invention have been fully disclosed as above. However, various modifications or replacements can be made by people skilled in the art based on the disclosure and teaching of the present invention without departing the spirit of the present invention. Therefore, the scope of the present invention shall not be limited to the above disclosed embodiments and should include said modifications and replacements.